GIESSLER

The Filtration Plant of the Champaign & Urbana Water Company

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THE FILTRATION PLANT OF THE CHAMPAIGN AND URBANA WATER COMPANY

BY

WILLIAM CARSON GIESSLER

THESIS

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

WILLIAM CARSON GIESSLER

ENTITLED The Filtration Plant of the Champaign and Urbana Water Company

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Municipal and Sanitary Engineering.

G. C. Habermeyer
Instructor in Charge

APPROVED: A. N. Talbot

HEAD OF DEPARTMENT OF Municipal and Sanitary Engineering.

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THE FILTRATION PLANT OF THE CHAMPAIGN AND URBANA WATER COMPANY

INTRODUCTION

The water supply for the cities of Champaign and Urbana is taken from fifteen wells in glacial drift driven and bored to depths of about 150 feet. The water from these wells contains a considerable amount of organic matter, very little if any oxygen and about two parts per million of iron in solution as ferrous carbonate. Upon coming into contact with air this iron is oxidiized and precipitated. The use of this water stains clothes and discolors plumbing fixtures. In addition to the above disagreeable features the presence of the iron encourages the growth of a microscopic filamentous plant known as crenothrix. This plant is not especially harmful to health, but it acts as an oxidizing agent and aids in the precipitation of the iron. Crenothrix does not require light and is found in abundance in the water mains, sometimes being in quantity sufficient to practically clog the smaller pipes. If the consumption of water is increased for any reason the velocity is increased and the result is the flushing out of the precipitated iron and crenothrix, which grows in the mains. This gives the water a very objectionable appearance.

As a result of the above disagreeable features of the Champaign-Urbana water supply, the following provision was inserted in an ordinance providing for a supply of water for the City of Champaign, passed by the City Council, April 19, 1910: -

"The water supply shall be artesian, pumped from deep bored or driven wells, and shall be wholesome and suitable for domestic use. The Company shall, within two years from the passage of the ordinance, install and thereafter maintain such necessary filters or other apparatus at its pumping station for the purpose of removing at least fifty per cent of the iron and other sediment from the water before pumping the same into the mains and the said filters shall be kept in operation."

PRELIMINARY INVESTIGATIONS

Investigations on iron removal from the local waters were made by Mr. W. G. Stromquist and Messrs. E. F. Blakeslee and A. L. Enger.

Mr. Stromquist's first investigation was for a thesis on the removal of iron from the University water supply. The following is a brief description of Mr. Stromquist's work.

Two samples of tap water were taken simultaneously in bottles. One bottle was shaken vigorously and the other was set aside without shaking. After standing for three days, the shaken sample contained 0.3 parts per million of iron and the other 0.8 which shows that aeration accelerates precipitation.

Water was run over an aerator which consisted of circular discs or rings, then thru a sedimentation tank and thru a filter. The results show that the dissolved oxygen was increased by the aeration from about 1 to 5 parts per million and that iron was not appreciably removed until it passed thru the sand filter where it was reduced from an average of 1.25 parts per million to

an average of .86 parts per million. The general results of the test with the mechanical filter indicate that it would be necessary to wash frequently, due to the rapid clogging of the filter.

Following the sand filter experiments preliminary filtration thru gravel was investigated by passing the water first over a funnel which served as an aerator and then thru bottles containing gravel graded as follows:

Bottle	Passing	Retained on
1	---	3/4 inch sieve
2	3/4 inch sieve	1/2 " "
3	1/2 " "	3/8 " "
4	3/8 " "	Number 3

After the apparatus had run 24 hours the sand was examined and it was discovered that there was a brown coating thruout. This coating consisted of dark brown filaments which gave an offensive odor and charred when treated with hydrochloric acid, all of which indicated organic matter. A microscopic examination showed the presence of crenothrix and other organisms. However, the outlet pipe of the sand filter was devoid of any coloration which indicates the removal of iron and crenothrix by the sand filter.

From his thesis investigations Mr. Stromquist came to the following conclusions: -

"That aeration and filtration can remove iron from this water.

"That the more thorough the aeration the better the results obtained.

"That sedimentation is of no advantage. The time required for sedimentation to become effective is so great that it would not be practicable to build reservoirs large enough to do any good.

"That a rate of filtration of 125,000,000 gallons per acre per day can be used as effectively as a slower rate, both for sand and gravel filters.

"That some preliminary treatment should be employed to relieve the first sand filter and reduce the frequency of washing the filter."

During the summer of 1910, Mr. Stromquist built a small experimental plant at the pumping station of the Champaign-Urbana Water Company and ran experiments on filtration thru gravel and sand with and without aeration and also experimented on washing the filters with and without air. As a result of these experiments he made the following recommendations to the Water Company in a report: -

Dissolved oxygen in the water should be increased to at least six or seven parts per million by means of aerators, to be attached to the discharge pipes of the deep well pumps and the aerated water should be pumped from the old reservoir, onto the filter by a centrifugal pump.

The water should be filtered thru sand filters at a rate of 125 million gallons per acre per day. The filters could be run 24 hours between washings with a loss of head of seven feet. The filters should be occasionally treated with bleaching powder.

In the spring of 1911, L. F. Blakeslee and A. L. Enger ran a series of experiments with the apparatus used by Mr. Stromquist and investigated the following points:

(1) Iron removal at different parts of the plant.

(2) Oxygen content at different parts of the plant.

(3) Loss of head while washing.

(4) Loss of head thru the underdrains.

(5) The effect of allowing the filter to stand idle.

After their work they came to the following conclusions:

Two or three parts per million of oxygen is sufficient to precipitate the iron if sufficient time and agitation is provided.

A sand filter containing sand, not much larger than that used in the experiment (effective size, .76 millimeters, uniformity coefficient 3.0) with a depth of filtering material of twenty inches will remove all the iron in the filters when the sand is clean.

The experiments already made do not give sufficient data to show that the filter can be kept clean of crenothrix for any length of time.

BRIEF HISTORY

With the data secured from the above investigations a filter plant was designed under the direction of Professor A.N. Talbot.

It was first planned to use 6 circular wooden filter tanks 12.5 feet in diameter and 15 feet deep. This design was considered on account of its cheapness but was later given up for the more permanent type of reinforced concrete construction.

As first designed the concrete filters were arranged in the form of a square. The advantage is the opportunity afforded for compact arrangement of piping and pumps. The disadvantage is that the operation of the two back filters cannot be observed without climbing upon the filter wall. This design was eventually abandoned for that of the present plant which was built during 1912 and 1913.

DESCRIPTION OF PLANT

The plan of the plant as finally built is shown in Figure 1. Each well discharges into a receiving reservoir of 250,000 gallons capacity. From this reservoir it is pumped by two 10 inch centrifugal pumps into the filters and after filtering flows into the clear water well which has a capacity of 750,000 gallons. From this well the water is pumped into the mains.

The filter plant is located between the receiving reservoir and the clear water well. As shown in Figure 1 , it consists of four units side by side, of reinforced concrete, 12 feet wide and 15 feet long inside dimensions. They will filter at a rate of 125,000,000 gallons per acre per day.

WALLS AND BUILDINGS:

The filters are rectangular and wholly above the surface of the ground. The total length over all is 56 feet and the width 18 feet. The average height over all from top of wall to base of footing is 13 feet 9 inches. The plant is built as two main parts, with an expansion joint between filters, number two and three. The footings were built first, then a cinder concrete fill for the bottom of the filter floor. The filter walls were then built on the footing in two monolithic sections. The walls are all 18 inches thick except the upper 5 feet 7 inches of the front walls which is only 12 inches

thick, to allow for the wash water outlet, and the wall between the two middle filters which is made of two 12 inch walls with an expansion joint between them. 1 - 4 - 6 cinder concrete is used in the fill. 1 - 3 - 6 concrete is used in the footing and 1 - 2 - 4 gravel concrete in the walls and floors. The lower three feet of the walls are reinforced with half inch round rods spaced 4 inches. In the upper seven feet the bars are the same size spaced 6 inches, as shown in Figure 6. The filters are made water-tight by a coating of 1 to 1 cement grout on the inner surface of the walls.

A cement floored gallery runs along the west side of the filter and is 14 feet wide for the full length of the filters.

The filter house is of brick with a frame roof. The brick work has been left rough so that the walls can be stuccoed which will give the house a more pleasing appearance.

CONTROL:

The operation of the filter is controlled entirely from a five foot platform in front of the filters and three feet below the top of the wall. Each valve has a wheel stand on this platform and all switches and controllers are within easy reach.

MACHINERY:

The raw water is to be pumped by two 10 inch American single stage centrifugal pumps. The suction of these pumps is a 12 inch cast iron pipe from the receiving reservoir. Since

raw water is to be used for washing, each pump is connected to wash water and raw water headers.

Each pump is belt driven by a 15 H. P. Wagner variable speed induction motor. These motors run on 220 volts furnished by the company's own plant.

Air for washing is supplied by a Connersville displacement blower of 2.06 cubic feet displacement per revolution. It runs at 240 r.p.m., with an estimated discharge of 360 cubic feet per minute.

The air blower is run by a 20 H. P. Wagner motor similar to the pump motors.

Each pump motor is controlled by a seven point General Electric controller of the resistance type.

PIPING:

Raw water is discharged from the pumps to an 8 inch raw water header running the full length of the filter gallery. At each filter there is a 6 inch branch which passes thru the wall near the north-west cover of each unit. Two feet inside the wall this 6 inch pipe rises vertically to an elevation of 9.5 feet above the center of the effluent pipe. On top of this vertical pipe there is a 4½ inch cast iron orifice. This orifice has been calibrated in the Hydraulic Laboratory of the University of Illinois. A 3/4 inch pipe is tapped into this 6 inch vertical pipe at a point 2 feet below the orifice and passes

thru the filter wall. A gage glass mounted on a calibrated scale permits the reading directly of the discharge of the jet in gallons per minute. This piping is shown on Figure 2 and 3.

The main drain of each filter is a 10 inch cast iron pipe running lengthwise of the filter. Every 6 inches along the top of this pipe there is a $2\frac{1}{2}$ inch tee into which two $2\frac{1}{2}$ inch lateral pipes connect. Robert's brass strainers are screwed into these lateral pipes every 6 inches. Outside the filter walls there is an angle to a 6 inch pipe which leads to the clear water well. A plan of the filter drains is shown in Figure 4.

The filters are to be washed by backward flow of raw water thru the under-drains, as shown in Figure 4. The discharge pipes of the pumps are connected to an 8 inch wash water header which also runs the length of the filter gallery. The discharge of the pumps into either the raw water header or the wash water header is controlled by two valves (Figure 3). An 8 inch pipe connects the 8 inch header with each of the 10 inch cast iron under-drains.

The removal of the wash water is by two structural steel troughs, which run lengthwise of the filter and are $5\frac{1}{2}$ feet center to center. The tops of the troughs are at an elevation of 7 feet above the center of the effluent pipe. The two troughs lead into a 10 inch outlet at the front of the filter which is connected by a 10 inch vertical pipe to a 10 inch header, under the floor of the gallery. The header runs to the

south end of the gallery where it has two outlets one leading to an 8 inch sewer outside the plant and the other thru an 8 inch pipe to the upper reservoir. By this means the latter part of the wash water can be run into the reservoir and saved.

The discharge pipe of the blower is 4 inches in diameter and leads to a 4 inch header which runs along the filters the full length. At each filter a 4 inch pipe rises just over the filter wall and runs to the center of the filter where it goes down to a 3 inch manifold pipe. This pipe is 6 inches above the main drain and parallel to it. Every 6 inches along the lower side of the pipe there is a 1/2 inch tee connection for brass lateral pipes as shown on Figure 5. These pipes have 1/16 inch holes drilled every 3 inches, on alternate sides of the pipe at an angle of 45 degrees to the vertical. These brass pipes are located between the strainers and direct the air downward at an angle of 45 degrees, with the horizontal. The quantity of air to be supplied is 360 cubic feet per minute and the estimated velocity from the 1/16 inch holes is 196 feet per second.

FILTERING MATERIAL:

Gravel of 4 millimeters effective size and uniformity coefficient of 2 was sifted on a coarse screen. The coarser portion was placed on the bottom and the finer gravel on top of it. On top of the gravel a layer of sand was placed of .3 millimeter effective size and uniformity coefficient of 5.0. This sand was placed in 6 inch layers and washed. One half to

one inch of clayey material and fine sand accumulated on each layer and was shoveled off. The depth of sand left on the filters is 30 inches, making 40 inches from top of sand to strainers. The top of the sand is 20 inches below the top of the wash water troughs.

TESTS

WASH DISTRIBUTION:

Several tests were made for distribution of pressure in washing. Four strainers were removed at the following point, as shown in Figure 4. (1) Just inside the west filter wall; (2) at the outer end of the first lateral pipes; (3) at the far end of the manifold pipe and (4) at the outer end of the last manifold pipe. A rubber tube and gage glass was attached to a 1/4 inch pipe, rising from each of these to above the wash water trough. The rise of water in these tubes above the surface of water in the filter when washing gave the difference in pressure between the water inside the pipe and just outside, or the loss in going thru the strainer. The tests were unsatisfactory, owing to several difficulties A true test would be one with a discharge of 1400 gallons per minute. Lack of water prevented wasting any into the sewer and the return pipe to the reservoir could not handle the discharge from the wash water troughs. The result was a very rapid rise of water in the filters and prevention of the securing of good readings. A second difficulty was with air in the vertical

pipes to the gage glass. The air could be removed by lowering the glass tube until water flowed from it but the rapid rise of water did not allow time for this and the securing of a reading.

The readings were so variable that it is hardly worth the space to present them here. An average of all seems to indicate that the difference of pressure inside and outside the manifold pipe at point No. 1, is about 28 inches and at point No. 3, it is about 45 inches when the pump is discharging about 1250 gallons per minute. The reading at points No. 2 and 3 were inconsistent, sometimes being less than the readings at the manifold pipe.

DISTRIBUTION OF AIR:

The distribution of pressure in the air system was investigated by taking pressure readings at four different points in filter No. 4, as shown in Figure 4, as follows;(1) center of the manifold pipe; (2) the outer end of the central lateral pipe, next to the filter wall; (3) the west end of the manifold pipe; (4) the north end of the west lateral pipe. One quarter inch pipes high enough to reach above the water were connected vertically at the above four points by means of pipe fittings and each was connected to a mercury gage by a rubber hose. Readings were taken with the filter empty, with it full of water to the troughs, and with the wash water running. It was found, with water in the filter up to the troughs, that the pressure was about three times as great as when the filter was

empty and that the water rising in the filter as when washing caused no appreciable increase in pressure. It was also found that with no water the pressure at points 3 and 4 was about 33 % greater than at points 1 and 2 and that water over the air pipes, either stationary or running made the pressure uniform over the entire filter. The pump gage read 1.2 pounds without water and 2.7 pounds with water and the pump ran at 240 r.p.m.

FILTRATION AND WASHING TESTS

On Thursday, May 22, 1913, at 5:07 p.m., filter No.1 was started at a rate of 350 gallons per minute and was run continuously for 48 hours. The table on page 17, and curve on page 30, show the results of the test. The lost head was measured by two gages, one connected to the filtered water effluent pipe and the other to the water above the sand in the filter. The difference between these elevations was the loss in filtering. The filter started with a loss of head of one foot and this increased at a fairly constant rate to a lost head of 7.65 feet, after running 48 hours. Reference to page 30 shows that the increase in the lost head was somewhat irregular. This can be accounted for by the fact that altho the rate of raw water inflow was constant the rate of filtration could not be maintained exactly constant by hand control.

The filter was allowed to stand submerged until 9;30 a.m., Sunday, May 25, 1913, at which time it was drained. A hole 18 inches deep was dug in the sand. The appearance of a cross section of the sand seemed to indicate that there was practically no iron below one foot beneath the surface and that it gradually increased to the top. The top inch seemed to contain from 80 to 90 per cent of the iron removed

The filter was washed by backward flow at a rate of 1400 gallons per minute. It was washed for six minutes without air and the wash water wasted into the sewer. The reason for

not using air at the start was on account of blower trouble. After seven minutes washing, the wash water was discharged into the upper reservoir thru the by-pass. It was run this way for 13 minutes, making a total time of washing of 20 minutes and a total waste of about 9000 gallons of water.

The first wash water contained 50 parts per million of iron, and at the time when it was turned into the reservoir it contained 3.5 parts per million which was decreased to a still lower amount at the end of the run.

Table 1

48 HOUR TEST OF FILTER NO. 1.

RATE - 350 gallons per minute, or 125,000,000 gallons per acre per day.

Date	Time	Lost Head, Feet	Iron Content Parts Per Million Raw	Iron Content Parts Per Million Filtered
May 22, 1913	5:07 p.m.	1.00		
	5:30	1.00	1.5	0.4
	8:00	1.50	1.5	Trace
	9:00	1.60		
	10:00	1.60		
May 23, 1913	6:00 a.m.	3.10		
	9:00	3.80	1.6	Trace
	10:30	4.00		
	3:00 p.m.	4.25	1.7	Trace
	5:07	4.55	1.7	Trace
	9:40	4.95		
May 24, 1913	8:50 a.m.	5.75	2.1	Trace
	11:00	7.00		
	2:00	7.65	2.2	Trace

The table on page 18 shows the iron content of the raw water and of the filtered water After 15 minutes run the raw water contained 1.5 parts per million of iron and the filtered effluent 0.4 parts per million After about an hours run the iron content in the filtered effluent was reduced to a trace. It was so small that a stardard could not be made up for it.

IRON DETERMINATION:

The determinations of iron in parts per million were made at the filter plant.

Standards for the test were made up by adding known quantities of ferrous ammonium sulphate solution of 20 grams per liter to 50 c.c. of distilled water in Nessler tubes.

Samples of the water were taken in 50 c.c. Nessler tubes. About 2 c.c. of diluted hydrochloric acid were added to the standards and samples, then about 2 drops of concentrated nitric acid. Addition of a small quantity of potassium sulpocyanide produced a red color, the intensity of which varied with the iron content. Comparison of colors of the sample and the standards indicated the iron in parts per million.

STRESSES IN FILTER WALLS

The stresses in the filter walls were determined as follows;

Concrete assumed as not reinforced.

Bars spaced 6 in.

Bars spaced 4 in.

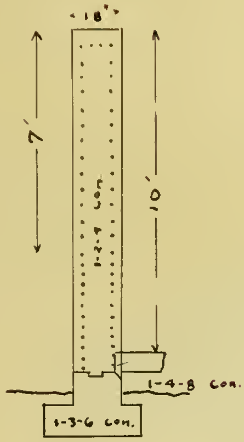


Fig.6

Depth of wall 10 feet.

Length of wall 15 feet.

Stress investigated at a point 7 feet from the top of wall.

Pressure = .434 X 7 = 3.03 pounds per square inch.

For a 1 inch strip 15 feet long.

$$\text{Moment at center} = \frac{1}{24} \times 3.03 \times (15 \times 12)^2 = 4100 \text{ lbs. in.}$$

$$S = \frac{M\,c}{I} = \frac{4100 \times 9}{\frac{1}{12} \times 1 \times 18^3} = 75 \text{ pounds per square inch.}$$

The stress at supports is twice that at center, or 150 pounds per square inch.

STEEL REINFORCEMENT:

Assuming the steel takes all tensile stress. The approximate distance between the center of gravity of the compressive stresses and the center of steel is $\frac{7}{8} \times 16 = 14$ inches. The area of steel per vertical foot of wall is .049 square inches.

$$S = \frac{4100}{14 \times .049} = 6000$$ pounds per square inch stress in steel at center of wall.

With single reinforcement at supports the stress in the steel

there would be twice that at the center, or 12000 pounds per square inch. Diagonal rods at the point take a part of this and the stress in the wall at the floor is relieved by the floor so the wall is quite safe.

Table II

PUMP TEST

Made April 24, 1913

Controller Point	Total Quantity Gallons per min.	Total Head, feet	R.P.M.	Remarks
5	1236	12.4	350	North Pump
6	1474	14.9	400	
7	1507	15.3	410	
7	1560	15.9	418	
4	1075	12.0	320	
5	1235	13.2	353	
6	1485	15.6	402	
3	980	11.7	300	
3	1020	10.7	310	South Pump
4	1095	12.3	328	
5	1245	13.5	360	
6	1425	15.15	400	
5	1245	13.6	360	
7	1480	15.9	410	
7	1035	25.5	422	Discharge valve partly closed.

Table III

PUMP TEST

Made May 8, 1913 North Pump

Controller Notch	Total Discharge Gallons per minute	Total Head Feet	R.P.M.
1	440	13.6	280
1	350	14.0	280
1	300	16.1	288
1	250	18.3	314
1	0	20.6	302
3	440	20.6	340
3	350	21.2	346
3	300	21.4	344
3	250	24.0	354
3	0	24.6	354
5	440	25.6	382
5	350	26.6	380
5	300	26.1	388
5	250	28.0	390
5	0	29.6	395
7	400	32.9	436
7	350	33.6	432
7	300	34.3	436
7	250	34.6	436
7	0	35.6	436

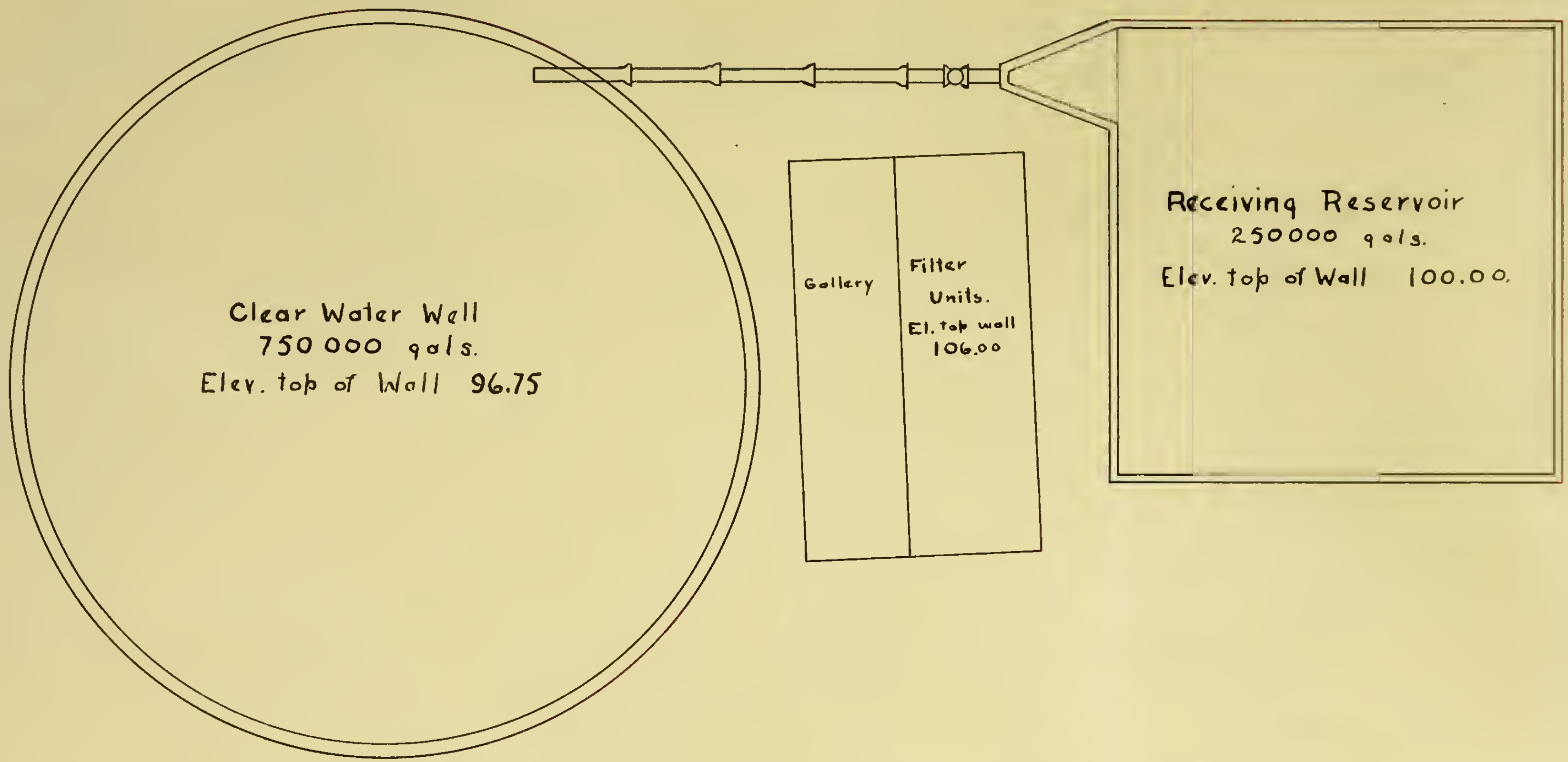
CENTRIFUGAL PUMPS

Experiments on centrifugal pumps in the Hydraulic Laboratory of the University of Illinois have given data from which it was found that the relation of the speed and head at any given discharge can be expressed by the formula $n = K (h + a)^{\frac{1}{2}}$ in which $\underline{K}$ is a constant for the pump, $\underline{h}$ is the total pressure head and $\underline{a}$ is a constant which varies with the discharge and represents the lost head in the pump. $\underline{K}$ was assumed as 75, 70, 65 and 60 and $\underline{a}$ was determined in velocity heads for each case from the data in Table II. It was found for this range that $\underline{a}$ varied as a straight line. Experiments show that there is some value of $\underline{K}$ for which $\underline{a}$ remains nearly constant. Investigation of the above data showed that when $\underline{K}$ is assumed as 60 the variation from the average value of $\underline{a}$ determined is only 2.5 per cent and when $K = 75$ the variation was 36 per cent. Using $K = 60$, the value of $\underline{a}$ would be 7 velocity heads, or $n = 60 (h + 7 \frac{v^2}{2g})^{\frac{1}{2}}$.

In the equation $n = k (h + a)^{\frac{1}{2}}$ for $\underline{a}$ we can substitute the values of $C Q^2$. When the values of $\underline{a}$ and $\underline{Q}^2$ from the data in Table II were plotted against one another it was found that the points fell on a straight line. Further investigation showed that the relation $a = .0000143 Q^2$ was true.

From this value of $\underline{c}$ a set of curves was made up (page 32). With $\underline{K}$ equal to 60 values for $\underline{n}$ and $\underline{Q}$ were assumed and $\underline{n}$ was solved for and plotted. From these curves the discharge can be estimated for any head and speed.

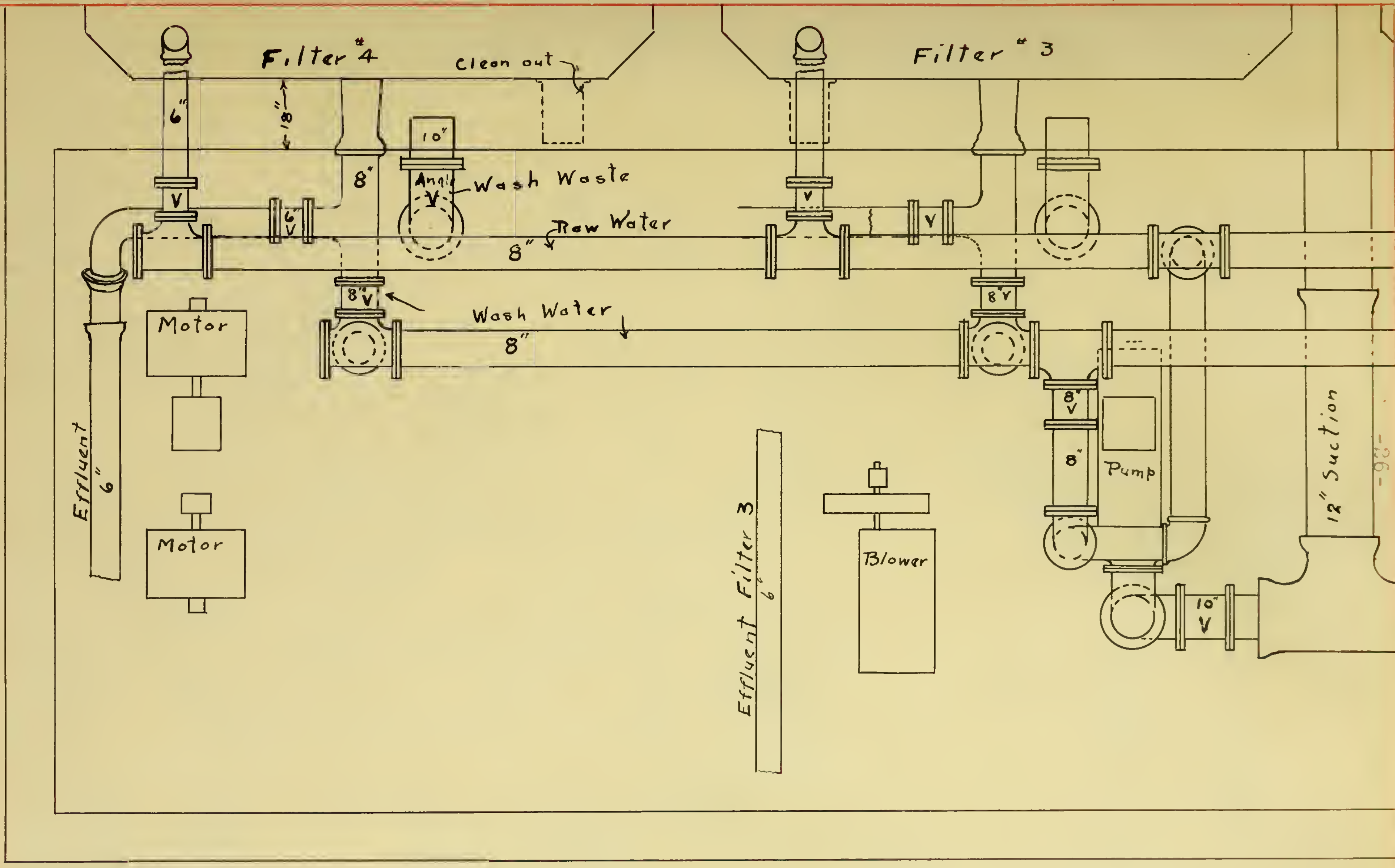
THE FILTER PLANT OF THE CHAMPAIGN AND URBANA WATER COMPANY.



Location of Units.

Scale 1 inch = 25 feet.

FIG. 1



Plan of North Half of Filter Gallery. Scale 1" = 3'

Fig. 2.

THE CHAMPAIGN-URBANA WATER PURIFICATION PLANT

Section of Filter Gallery

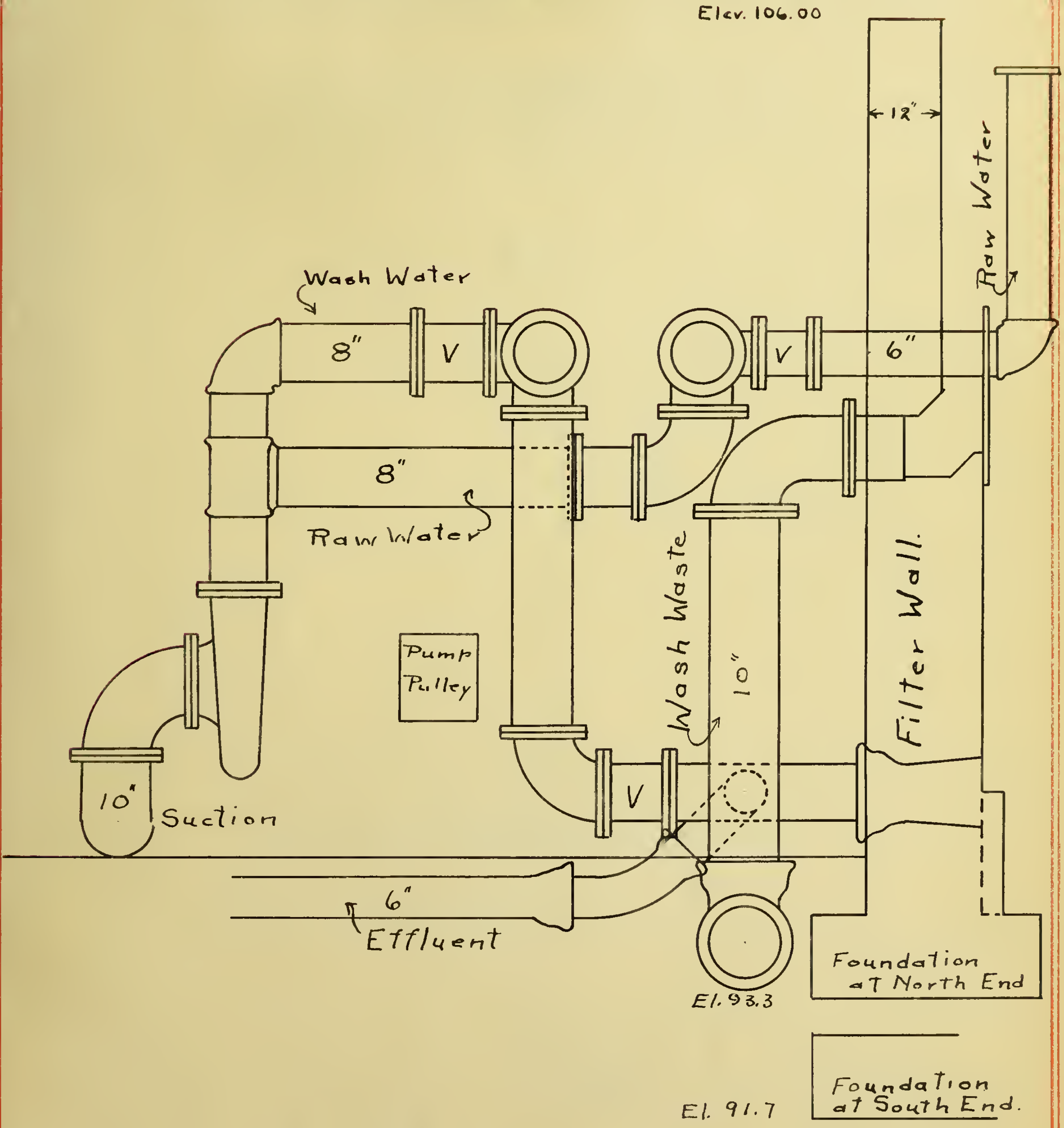
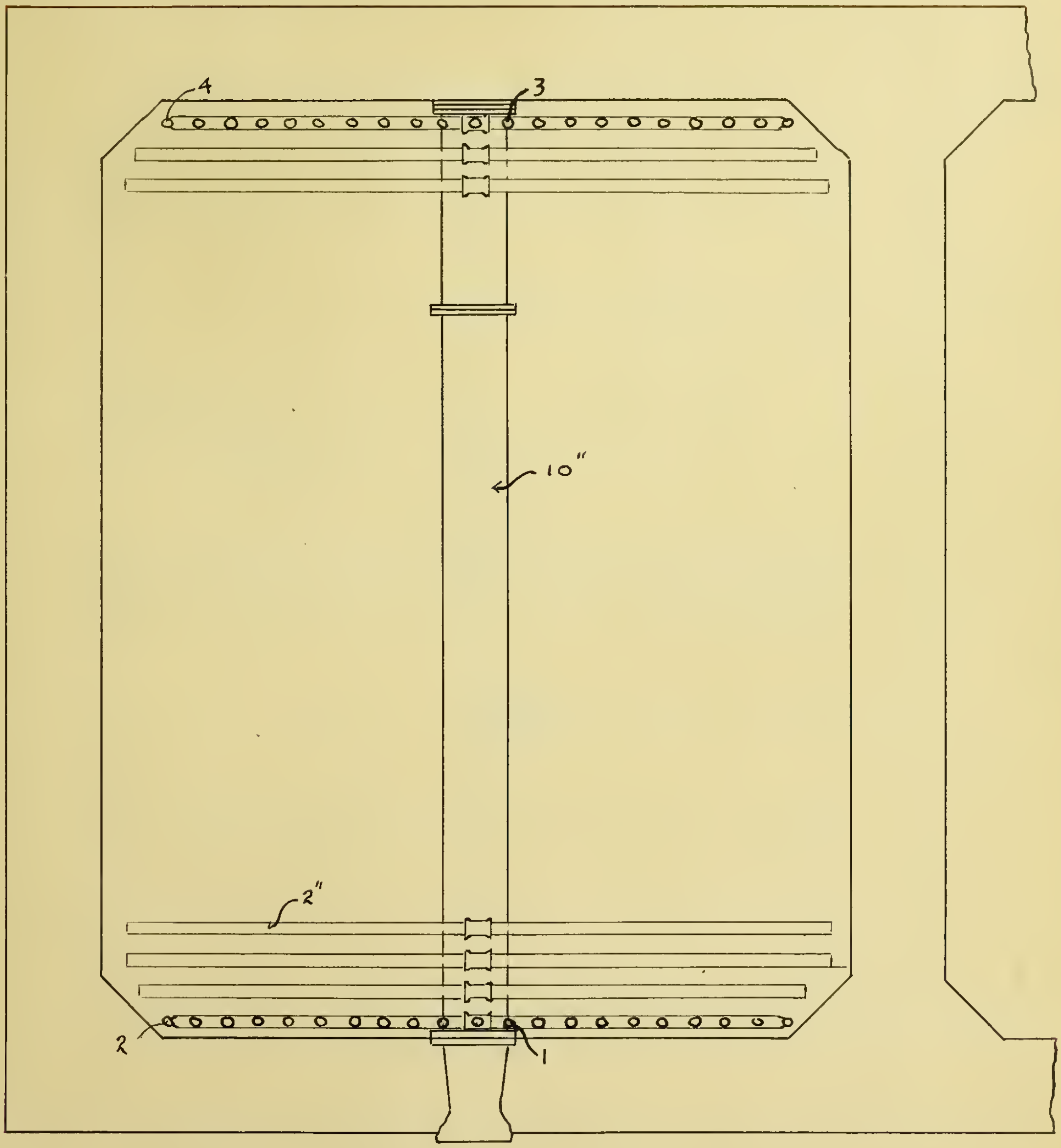
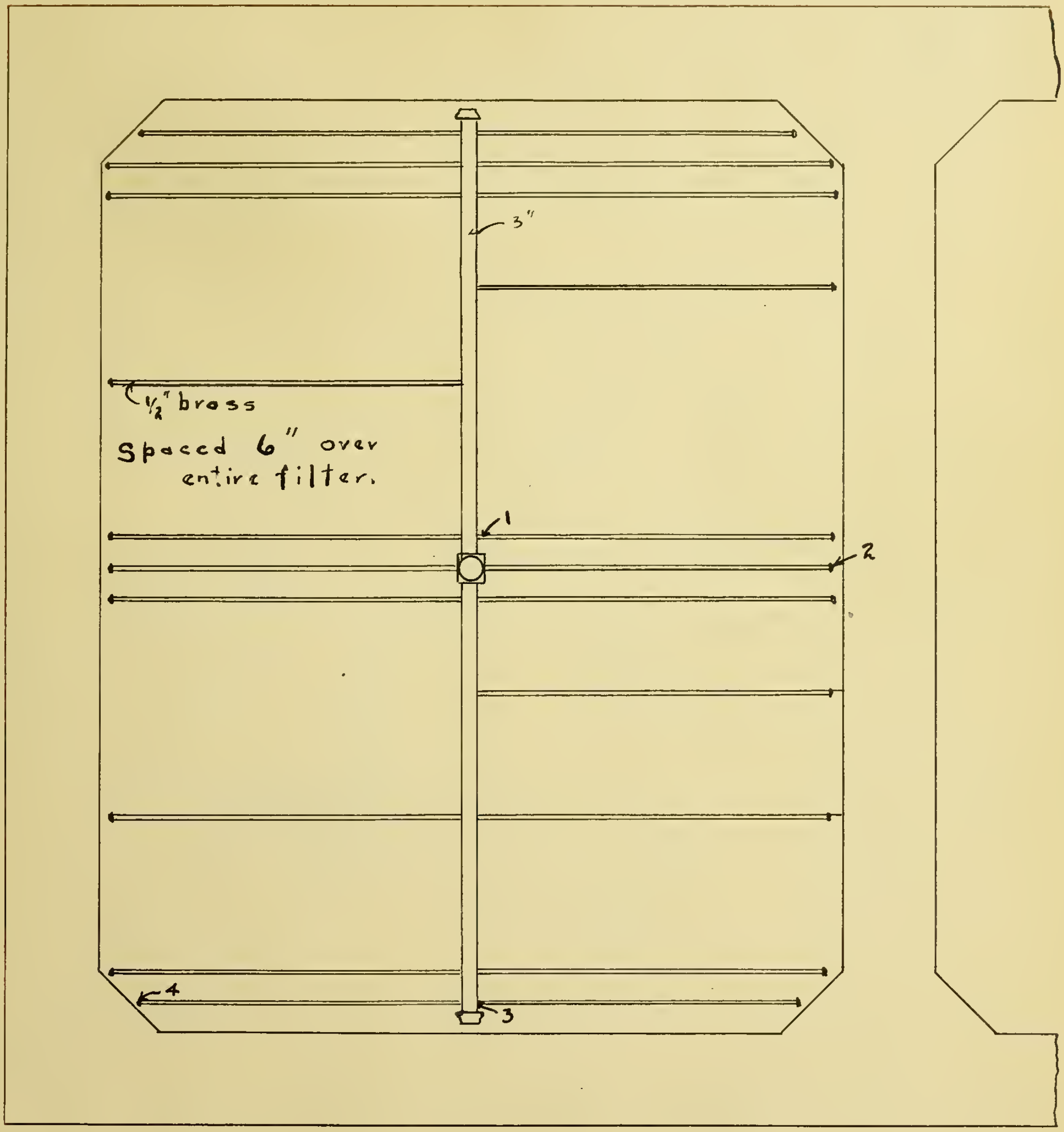


FIG. 3.



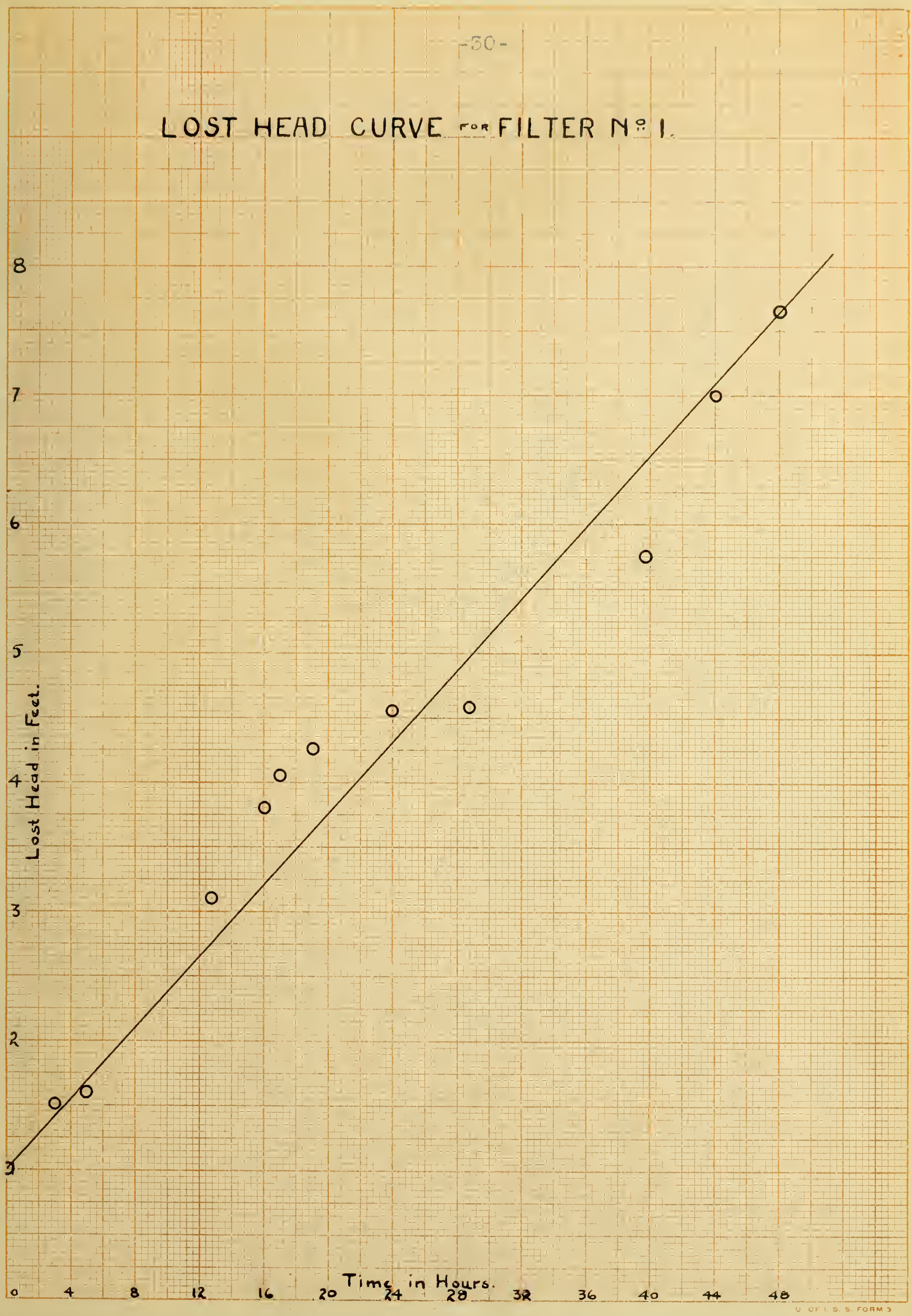
Plan of Filter No. 4 showing Collector Pipes and Location of Test Gages for Distribution of Pressure Scale 1 in. = 3 ft.

FIG. 4.

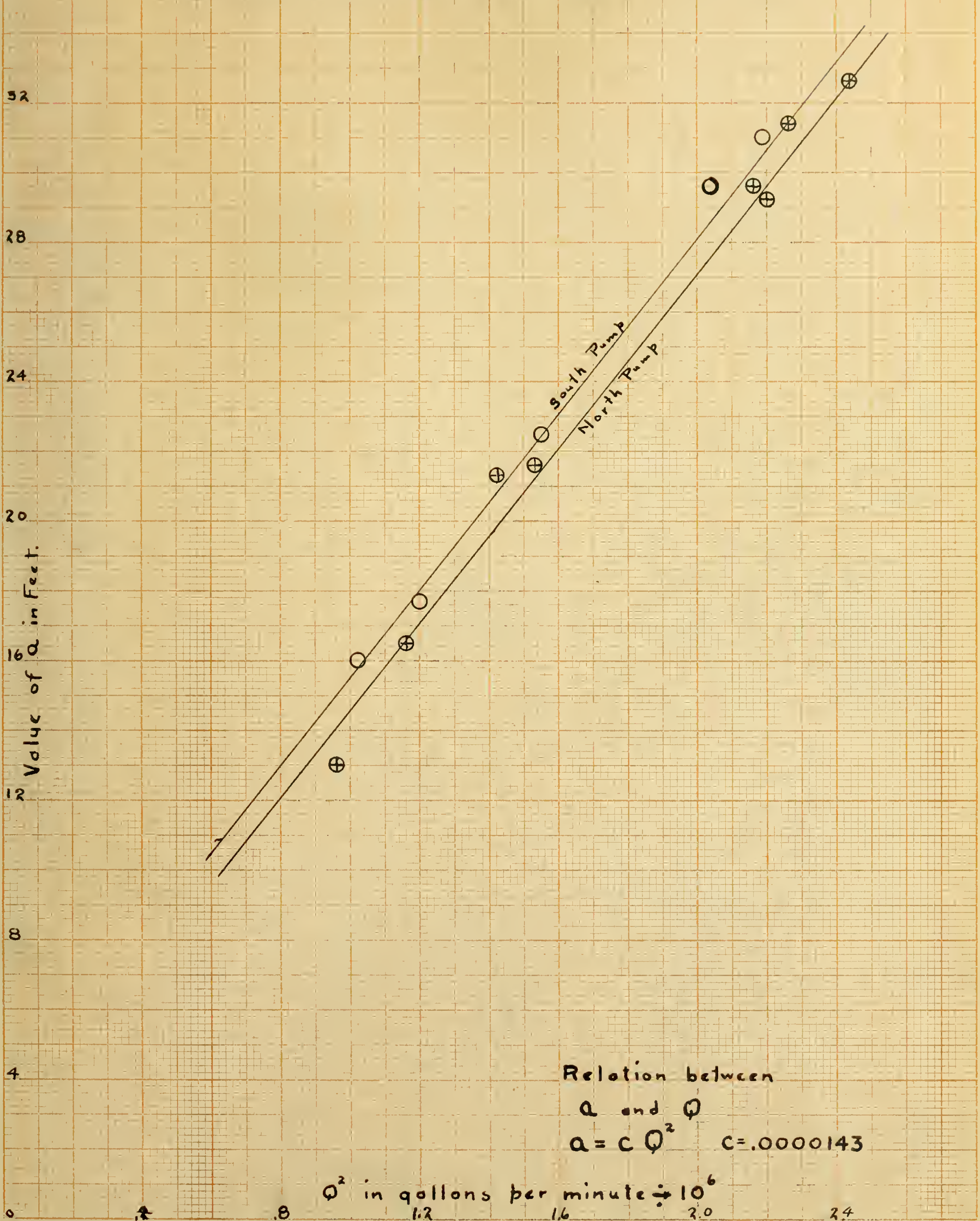


Plan of Filter No. 4 showing Air System and Location of Tests for Distribution of Air Pressure Scale 1 in.=3 ft.

FIG. 5.


LOST HEAD CURVE FOR FILTER No. 1.
Lost Head in Feet.
Time in Hours.
0
1
2
3
4
5
6
7
8
0
4
8
12
16
20
24
28
32
36
40
44
48
U. OF I. S. S. FORM 3

AMERICAN 8 INCH CENTRIFUGAL PUMP



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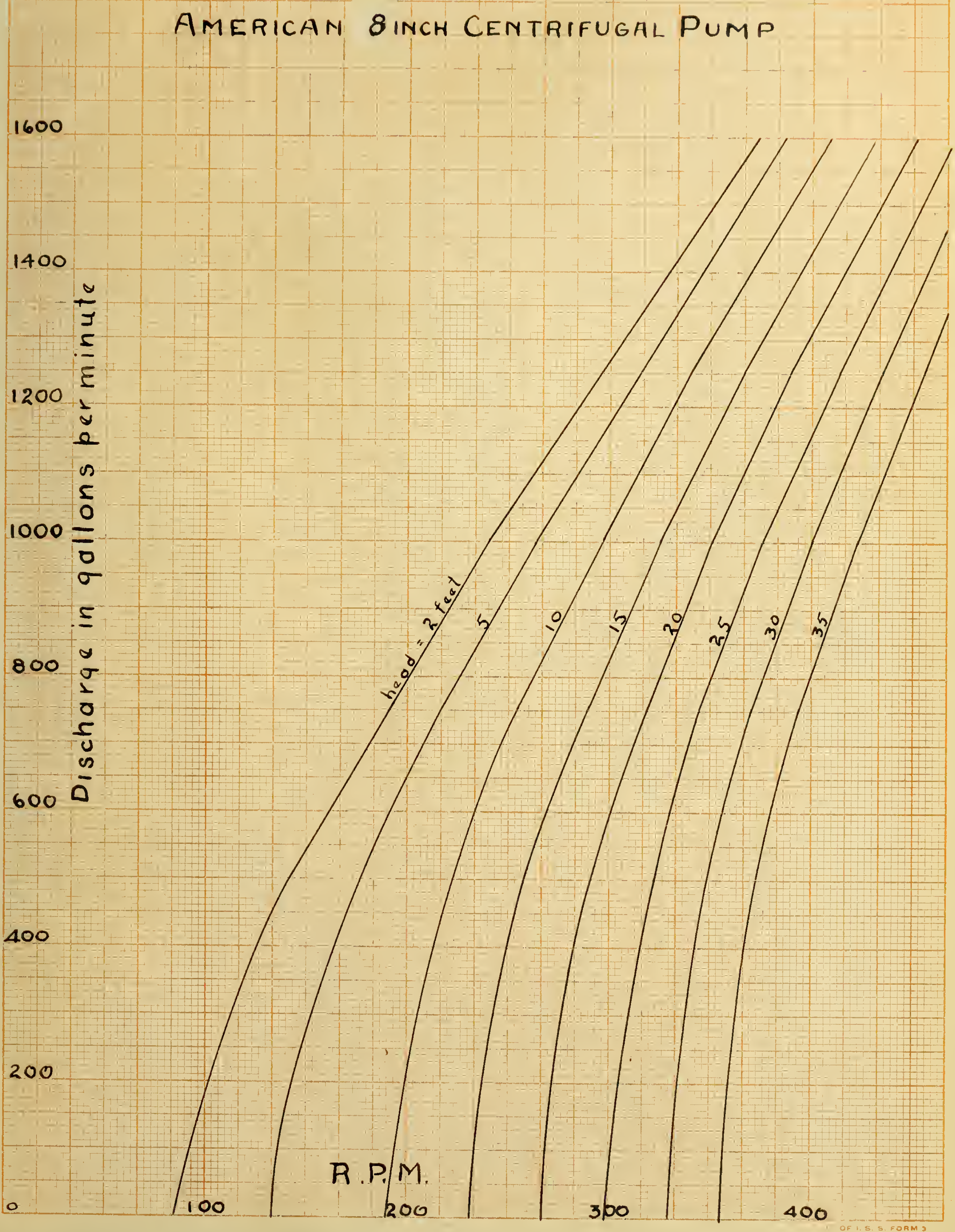

American 8 inch Centrifugal Pump
Discharge in gallons per minute
1600
1400
1200
1000
800
600
400
200
0
head = 2 feet
5
10
15
20
25
30
35
R.P.M.
100
200
300
400